Study of Haze in the Los Angeles Basin Using Reagan Sun Photometer Data

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I. Introduction

Reagan sun photometers are used in AVIRIS calibration experiments to track the sun and measure optical depth. From these measurements we can calculate an approximate visibility (in km). The AVIRIS Calibration and Validation team wanted to better understand the accuracy of the sun photometer calculated visibilities. Two experiments were conducted with the Reagan Sun Photometers to compare their visibilities with other sources. The first compared the sun photometer calculated visibility with visibilities reported by National Weather Service (NWS). The second compared the sun photometer data with data from an AVIRIS over flight.

II. Experiment 1

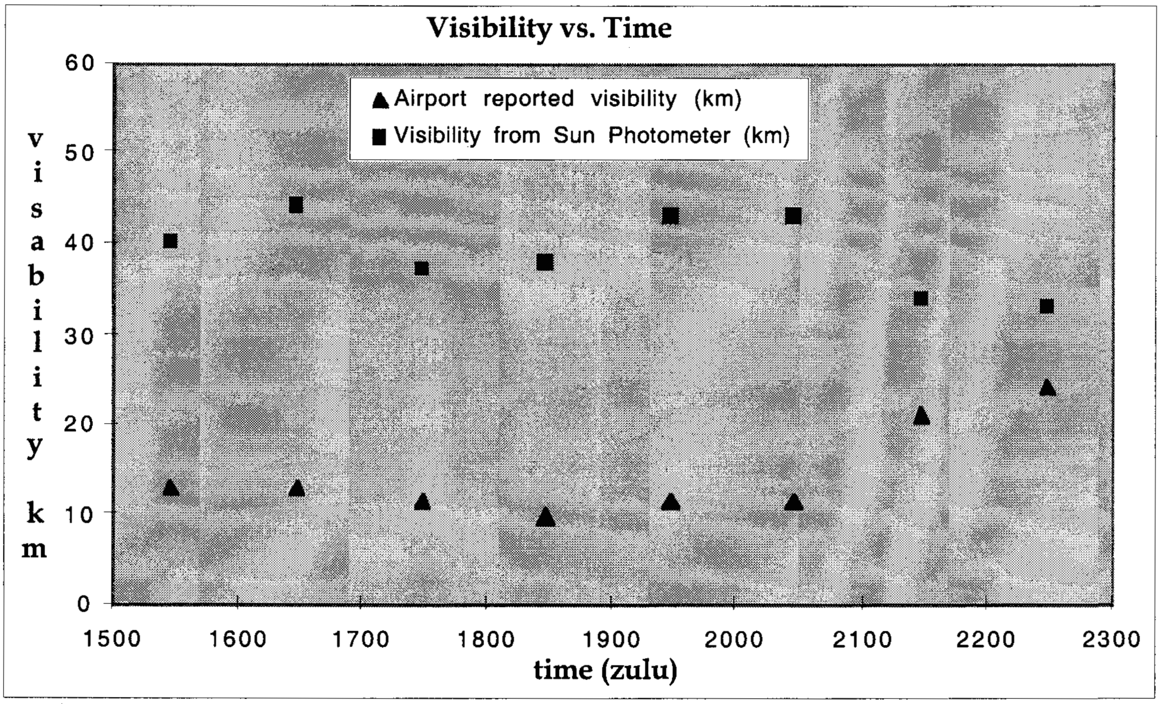
El Monte Airport

On August 3, 1999 two members of the AVIRIS Calibration team, set up a sun photometer at El Monte Airport.

Figure 1: Location of El Monte Airport

The goal of the experiment was to compare the visibility data of the sun photometer with the hourly reported visibilities of the airport. We hoped that this comparison would give us a better grasp of the accuracy of the sun photometer data.

Figure 2: Graph of Visibility vs. Time (Zulu) of sun photometer measurements and airport reported visibilities.



Sun photometer data is taken as the instrument traces the sun's path in the sky. In other words, the sun photometer is always looking directly at the sun as it takes measurements. During sunrise and sunset, the sun photometer is looking almost horizontally at the sun; however, at solar noon the sun photometer is looking almost vertically. So the direction that the sun photometer is looking while taking measurements is constantly changing, and therefore the amount of atmosphere that the sensor is looking through is also changing.

The airport reports the visibility when looking in the horizontal direction. The horizontal visibility is less than the vertical visibility because when one looks in a horizontal direction one is looking through more of the haziest part of the atmosphere than if one is looking directly up. Therefore, we expect the sun photometer visibilities to be more like the airport reports during sunrise and sunset. As the sun approaches noon, we would expect the sun photometer to report higher visibility than the NWS, since it will be looking through a minimum quantity of haze.

At first we thought this differing way of measuring visibility accounted for the results in Figure Two. A closer look at the graph showed us something else. At the beginning of the day the sun photometer and airport visibilities are closer together than they are at the middle of the day, however at the end of the day they are the closest. We expected this result was due to the elevation angle of the sun being less at the end of the day then ~~it~~ at the beginning of the day (ie, the sun was closer to the horizon at the start than the end of the experiment). However, this was not the case.

Figure 3: Graph of Visibility vs. Time with Sun Angle Superimposed.

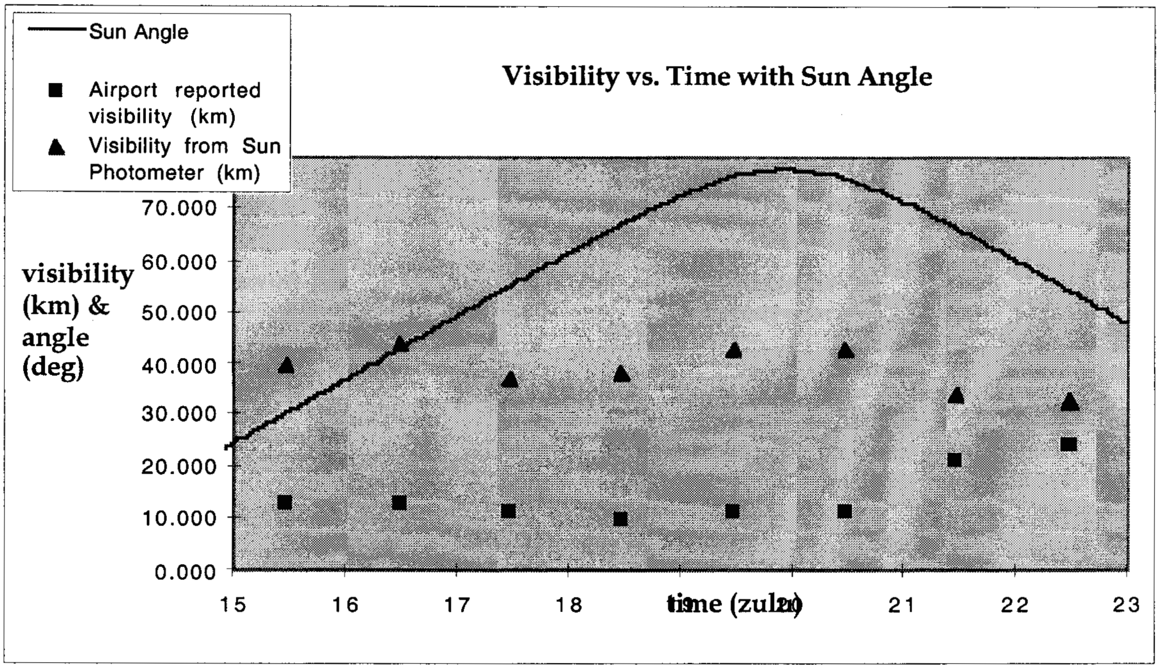


Figure three shows both visibilities, however it also has a graph of Sun Elevation Angle throughout the day. The sun angle was much smaller at the beginning of the day (30°) then at the end of the day (54°). Our original reasoning for the shape of our visibility curve is contradicted by these findings.

There are several other aspects of this experiment that we should consider. We usually use a Langley technique to calculate sun photometer visibilities, which assumes that the atmospheric conditions stay relatively constant throughout the day. However when we look at the airport reports we see that the visibility varied substantially over the day. These visibilities were taken in the same direction throughout the day, and so we can conclude that the atmospheric conditions were not constant. Because the conditions changed, the Langley-derived visibilities are probably not precisely accurate.

There is another method to that we can use to calculate the sun photometer visibility, the manufacturer-derived calibration coefficients. This method does not depend on stable atmospheric conditions, however it does make the assumption that the instrument response has remained constant since calibration by the manufacturer (University of Arizona). Because sun photometers, like all instruments, may ~~deviate~~ from their calibration over time, we decided not to depend on the ?? calibration coefficients when calculating visibility. Another problem with this method is that it assumes that conditions like detector temperature and power supply volatge are also constant. When either of these factors vary, the instrument response becomes unpredictable, and the manufacturer-supplied coefficients give inaccurate results.

We do not yet understand how to directly compare the calculated sun photometer and the airport reported visibilities. We do, however, have a better understanding of these different methods of finding visibility. The visibility reported by the NWS is the visibility when looking horizontally. This report should not be used in experiments, like AVIRIS over-flights, where vertical visibility is needed, for there is no simple way to compare these visibilities. Sun photometer calculated visibilities depend on an assumption of constant weather or instrument conditions. In a typical ground truth experiment, it difficult to quanitfy how consistant both the weather and instrument conditions are during the experiment. Although the weather appeared to be stable on the day of the El Monte Airport experiment, the visibility varied throughout the day; a Sun Photometer can appear to be running properly, yet because of a low or varying power source, vary from its calibrated response.

We are continuing to investigate the results of the El Monte Airport Experiment, and plan to determine if there is a way to directly compare the two visibilities.

III. Experiment 2

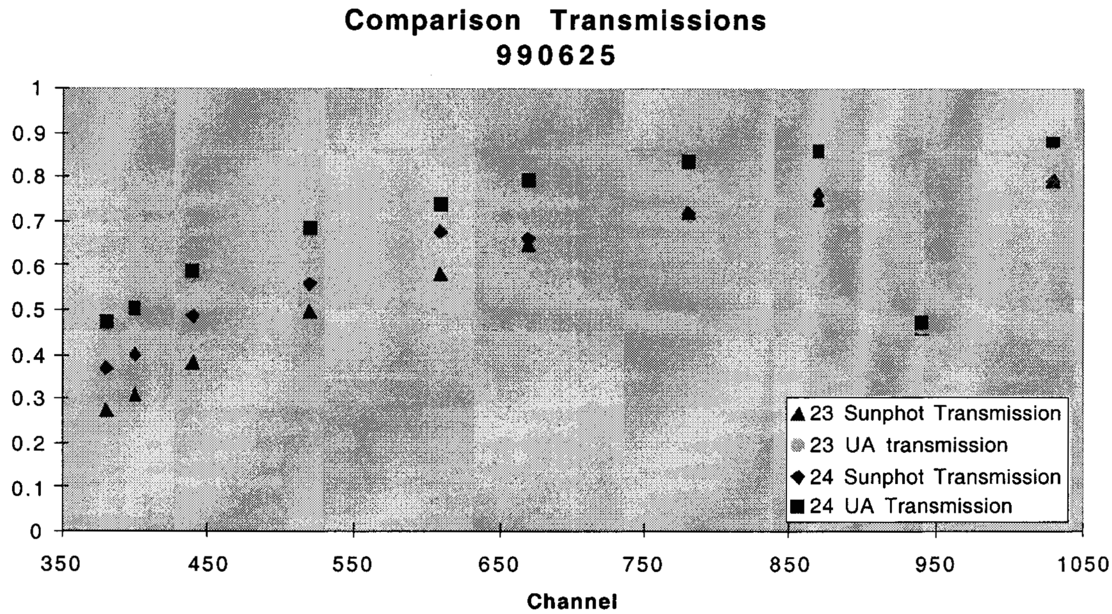
Mount Wilson

The AVIRIS Team set up an experiment to measure the haze levels in the Los Angeles basin near the Jet Propulsion Lab (JPL), and compare them to aerosol visibility values that we might obtain from AVIRIS data. We set up two sun photometers, one on the top of Mount Wilson (meters altitude) and one at JPL (meters altitude) to measure the visibility at each location. By comparing the two visiblities we can determine the difference in visibility due to haze at each location. This difference allows us to better understand the vertical distribution of haze in the basin.

Figure 4: Location of Mt. Wilson

Before we could conduct this experiment we needed to make sure that the sun photometers were transmitting comparable data. To do this we set up both sun photometers at the Jet Propulsion Laboratory on June 25, 1999. We then calculated the extraterrestrial constant (Vo) for each photometer using a Langley plot of Air Mass vs. natural log of the voltage. The exo-atmospheric constants were inconsistent with previous values. Noting this, we then compared the resulting visibilities to those obtained using coeffients provided by the manufacturer, University of Arizona (UA).

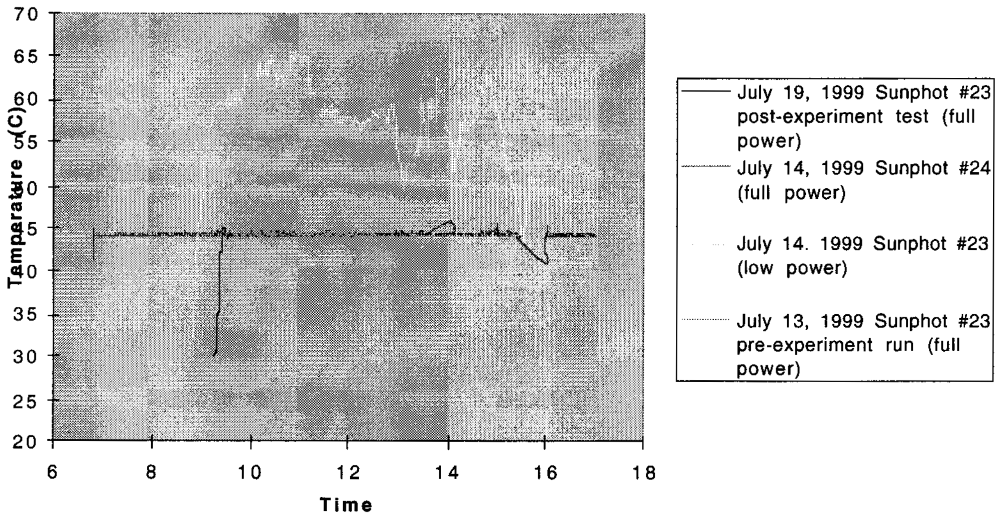
The following is a graph of the UA and JPL transmissions (transmissions that use coefficients determined by the Langley technique) of both sun photometers numbered 23 and 24.



The transmissions using the UA-derived coefficients match almost perfectly between the two sun photometers. Because these transmissions match so closely we can directly compare the data from the two sun photometers if we use the UA coefficients. It is interesting to notice that the Langley-derived transmissions match for the higher channels (from 650 on) yet do not match for the earlier channels. Also note that the Langley transmissions are both lower than the UA-coefficent transmissions.

On July 14, 1999 we took one sun photometer (#23) up to Mount Wilson and set up the other sun photometer (#24) on the roof of building 306 at the Jet Propulsion Lab in Pasadena. This was a "dry run" for a future experiment in which these observations will be combined with an AVIRIS overflight. Both sun photometers ran all day long and appeared to be taking data all day. When we looked at the data we found that the Mount Wilson sun photometer had very odd temperature readings. A normal reading for temperature is fairly constant throughout the day, however this sun photometer had temperatures that were varying significantly. After talking to technical personnel at University of Arizona we discovered that low power often results in inaccurate temperature readings. We also were informed that low temperatures could result in inaccurate data. The following is a graph of temperature vs. time of the #23 sun photometer when it has a full power supply and on July 14, 1999 when there was insufficient power, perhaps due to an undercharged battery.

Temperature Comparisions



As you can see the temperature readings for sun photometer #23 on July 14, 1999 vary much more than the other sun photometer temperature readings. Low power is the most reasonable explanation for this variance considering the sun photometer #23 had normal temperature readings for both the pre-experiment test on July 13, 1999 and the post-experiment test on July 19, 1999.

Because the temperature readings for sun photometer 23 on July 14, 1999 are varying it is unclear whether the data from that day is accurate or not, however the following are graphs of the transmissions for sun photometer #23 and #24 on the date of July 14 ,1999.

Sun Photometer Transmissions
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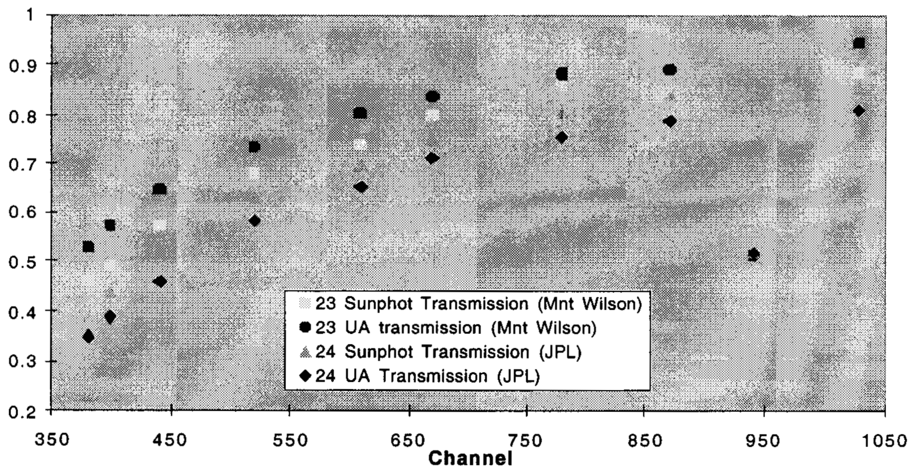
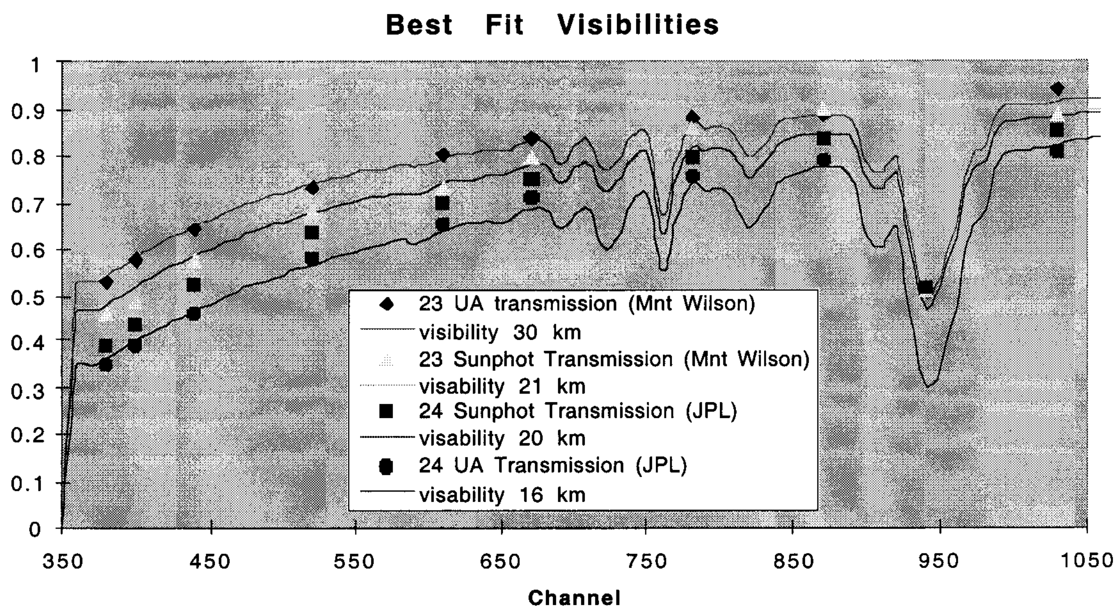


The most interesting and unexpected result from these transmissions graphs is the comparative Langley transmissions and UA transmissions. For sun photometer #23 the UA transmission was higher than the Langley transmission, yet for sun photometer #24 the UA transmission is lower than the Langley transmission. This is odd because in the June 25, 1999 Comparison experiment the UA transmissions were higher than the Langley transmissions for both sun photometers. This inconsistency could be attributed to the temperature/low battery problem, however further examination of sun photometer behavior will need to be done in order to determine the cause.

Once we had the sun photometer transmissions we used Modtran to determine the visibility. The best-fit visibilities for each of the transmissions are shown in Figure below.



We can directly compare the #23 and #24 data if we assume that the sun photometer #23 was taking good data despite its weird temperature readings. If we directly compare the data we find that the visibility is 14 km better on top of Mount Wilson.

The Mount Wilson Experiment helped us better understand the problems that can result when evaluating sun photometer data when the instrument conditions are unstable. Under normal circumstances, the two sun photometers could be directly compared to each other; however, because of low voltage we can not necessarily compare the results from this day. Because inconsistent instrument conditions are a reality, it is important to have ways of evaluating data that do not depend on these conditions. Unfortunately, when the atmospheric conditions may be changing, the Langley approach may also give inaccurate results.

This experiment will be repeated during the next AVIRIS flight season, in conjunction with an AVIRIS overflight of the same area. The AVIRIS data will be compared to the sunphotometer-derived visibilities in the areas of interest. The eventual goal is to determine if visibility can be determined directly from AVIRIS data, without the need to rely on ground truth observations.

Conclusions:

There are several techniques to determine atmospheric visibility for the purposes of atmospheric correction. The simplest technique is to rely on NWS data, if it is available. However, this data may not be representative of the sensor observation path if the atmospheric aerosols are strongly stratified, as they often are in the LA Basin. This has led to the use of sun photometer ground truth measurements to provide more reliable estimates of atmospheric visibility relevant to remote sensing instruments. The conversion from detector voltage to atmospheric depth (and thus, transmission) can then be accomplished by relying on manufacturer-supplied calibration coefficents, or by determining the coefficients directly from the data itself. Both techniques have advantages and disadvantages: the Langley technique does not require the instrument response to be remain stable since leaving the manufacturer, as long as it remains constant throughout any given experiment. However, it does depend on constant atmospheric conditions throughout the day. Conversely, the manufacturer-supplied coefficients do not require atmospheric stability, but rather instrumental stability. Which technique is most appropriate for any given experiment should probably be determined by the investigators. The final technique would be to determine atmospheric aerosol concentration directly from AVIRIS data itself. We are investigating several approaches to this problem, and hope to test them against sun photometer and NWS data during the coming flight season.

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